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Principles and Practice of Lentil Production

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Abstract

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Lentil (*Lens culinaris* Medik.) has not been researched as extensively as many other pulse (grain legume) crops. Until recently, most lentil cultivars had been developed by pureline selection from local germplasm collections. However, breeding programs have been established at several centers and have been successful in developing improved cultivars from hybridization and selection. The large, international, and multidisciplinary crop improvement program based at ICARDA in Syria has strengthened regional and national programs in many countries. While these resources provide opportunities for research and development on a far greater scale than in the past, there remain many researchers who are unfamiliar with the crop and many farmers who do not fully appreciate the constraints that must be overcome if yields are to be stabilized and improved. This publication describes various aspects of the crop, reviews the culture of lentils in the United States and worldwide, and advocates greater cooperation, collaboration, and communication among researchers, breeders, administrators, producers, and the various sectors of industry in general.

Keywords: grain legume, *Lens culinaris* Medik., lentil, pulse crops.

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Principles and Practice of Lentil Production

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Grain legumes are important dietary constituents worldwide even though their overall production lags far behind that of the cereals. Yields per unit area are generally less than one-half those of the major cereal grains. There are several reasons why grain legume yields in general and those of lentil (*Lens culinaris* Medik.) in particular have lagged behind: relegation of these crops to poorer soils, minimal research efforts until very recently, and various abiotic and biological limitations. The biological constraints relate to the large amounts of energy needed to absorb large concentrations of protein, and sometimes oil, into seeds in contrast to the energy required by cereals, which primarily store carbohydrates. Also, photorespiration consumes about 30 percent of the products of photosynthesis, and the symbiotic relation between the *Rhizobium* microsymbiont and its legume host reduces production potential by about 10 percent, as the plant diverts carbohydrates to nodulated roots for use during dinitrogen fixation (Evans 1980, Hymowitz 1987).

Energy requirements are critical for legumes because of their indeterminate growth and progressive flowering and seed-setting habits, compared with the synchronous flowering of cereals (Evans 1980). In addition, grain legumes are often grown in marginal arid areas where they seldom receive fertilizer, irrigation, or pest control chemicals. Indeed, they are often not planted or given agronomic care until cereal crops have been well established (Summerfield 1981b).

Research and breeding efforts devoted to legume crops are small compared to those devoted to cereals. For example, the number of accessions in germplasm collections of major cereals is up to one order of magnitude larger than those of legumes. There is great discrepancy, too, in the number of breeders working

with legumes compared to the cereals. For example, there are at least 10 times as many maize breeders as there are soybean breeders in the United States (Hymowitz 1987). Despite these imbalances in resources, remarkable progress in applied legume science and legume breeding has been made in recent years, especially in tropical regions, due primarily to the work of the system of international agricultural research centers (the CGIAR). The International Center for Agricultural Research in the Dry Areas (ICARDA), in Syria, is the unit within CGIAR with a world mandate for lentil improvement. It is widely expected that plant breeding efforts at ICARDA and in national programs elsewhere will lead to substantially increased lentil yields.

Cereal production worldwide exceeds that of grain legumes by at least 30 times; cereals occupy about 10 times more land and, on average, are 3 times as productive (table 1). Lentils contribute about 4.6 and 2.5 percent, respectively, to the supply of edible pulse crops worldwide and in the United States (Food and Agricultural Organization 1991).

A description of the lentil crop, together with methods of production, available cultivars, and crop improvement efforts, are reviewed herein.

Background

Production of Lentils in the United States

Grain legume crops contribute significantly to the total farm income in the United States. Grain legumes are produced commercially in 10 of the 50 states, while 95 percent of the national lentil crop is produced in just 2 states, Washington and Idaho (Morrison and Muehlbauer 1986) (table 2).

Lentils have been grown commercially in the Palouse region of eastern Washington and northern Idaho since 1937 (Youngman 1967). The Palouse includes the region of loess rolling hills with elevations up to 900 m (3,000 ft) and spanning 46–48 °N latitude. The higher elevations of the Palouse are located in an area of northern Idaho known as the Camas Prairie. Although the number of farms have decreased in recent years,

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Table 1. Area harvested, average seed yield, and production of selected cereal and grain legume crops in the United States and worldwide, 1990

Crop	Area harvested (ha)		Average seed yield		Production	
	US (1,000 ha)	Worldwide	US	Worldwide (kg/ha)	US (1,000 t)	Worldwide
Cereals						
Wheat	28,066	231,548	2,656	2,570	74,534	595,149
Rice (paddy)	1,138	145,776	6,473	3,557	7,027	518,508
Barley	3,035	71,483	1,889	2,524	9,119	180,437
Maize	27,024	129,116	7,437	3,682	201,509	475,429
Oats	2,404	21,841	2,156	1,999	5,184	43,665
Millet	150*	37,565	1,200	794	180*	29,817
Sorghum	3,674	44,352	3,951	1,312	14,576	58,190
Rye	151	16,562	1,679	2,235	257	37,007
Grain legumes						
Dry beans	844	26,407	1,693	617	1,471	16,294
Dry broad						
Faba beans	—†	3,201	—†	1,347	—†	4,312
Dry peas	64‡	9,267	1,688‡	1,890	108‡	17,511
Chickpeas	6‡	9,577	900‡	718	3‡	6,876
Lentils	42	3,191	943	844	40	2,692
Soybeans	22,865	56,339	2,287	1,913	52,303	107,767
Groundnuts (in shell)	729	19,968	2,242	1,157	1,634	23,109

* FAO estimates; see qualifying information in original publication.

† No information available.

‡ Unofficial estimate.

SOURCE: Food and Agriculture Organization 1991.

Table 2. Annual production of lentils in the United States by state, 1985–1990

Year	Washington* (1,000 t)	Idaho†
1985	29	8
1986	62	24
1987	53	29
1988	27	14
1989	29	23
1990	27	13

* Washington agricultural statistics (1985–1990).

† Idaho agricultural statistics (1985–1990).

the areas sown to lentils have increased. These increases reflect the rising demands from foreign markets, as well as those of an expanding domestic market. In 1990, lentil exports from the United States increased by 15 percent and had a value of \$31.7 million; the corresponding domestic market value was then \$6.8 million (USA Dry Pea and Lentil Council 1991).

Although yellow cotyledon lentils are widely grown in the Palouse for the domestic market and for export, there is increasing interest in seed types more common elsewhere. The smaller seeded “Persian” type with red cotyledons, popular in many areas of the Middle East, has generated considerable interest among American producers.

National pulse production areas are similar in climate, weather, and cultural practices. Lentil production is also under way on limited hectarage in areas such as northwestern Montana and eastern North and South Dakota. Continued expansion into these areas will depend on the attitudes of producers, the availability of farming machinery and equipment appropriate for the crop, and, ultimately, the relative profitability and certainty of return compared with alternative crops.

Lentils are most often grown in rotation with cereals. Farmers consider lentils an important factor in their rotations for several reasons: (1) soil erosion is reduced when a lentil crop replaces summer fallow; (2) less severe disease infestations occur in any following cereal crop because lentils are not an alternative host for certain cereal pathogens; (3) the rotation provides

better control of grassy weeds compared with cropping systems containing only cereals; and (4) lentils fix dinitrogen when effectively nodulated, thus reducing the demand for nitrogen fertilizers and the depletion of inorganic nitrogen from soil.

Optimum lentil production depends on carefully considered and prudently selected combinations of cropland, seedbed preparation, pest control, and timeliness and method of harvest. Lentils are commonly sold in volatile markets, making informed and astute marketing strategies an important feature in overall profitability (Smith 1980). Lentil exports vary in direct relation to crop production. Production is heavily dependent on environmental conditions, as the lentil crop is acutely sensitive to the vagaries of weather and climate.

The International Scene

American producers who are familiar with the crop and who are accustomed to yields more than double those achieved in many other countries may be surprised to learn that until recently there were no global, regional, or even national studies of trends in lentil production or the reasons underlying those trends. The first appraisals of the international status and the future potential of the crop were in a report by Watson (1979) and in a review of the role of cooperatives in marketing pulse crops in the United States by Smith (1980). World lentil production increased 53 percent during the 1980’s until 1990, due to increases in total area sown to the crop and in overall yield per unit area (Food and Agricultural Organization 1991). India and Turkey are by far the world’s largest producers (table 3). All the major lentil-producing countries, except Canada and the United States, are also major consumers.

Lentils can tolerate extreme environmental conditions of minimal rainfall and hot temperatures, although sensitivity to these stresses, particularly during flowering and fruit set, can have serious effects on yield. The crop is able to tolerate drought better than waterlogged soil. Worldwide, a large proportion of the lentil crop is grown in semiarid regions without the benefit of irrigation. In most of those regions where lentils are important, agriculture depends on water conserved in the soil after fall and winter rains. Lentils tolerate cool temperatures and can be sown in autumn in some of the warmer regions. They are, however, intolerant of

the extremely cold, dry winters in some regions. There is considerable work being done in the United States and Turkey, and by ICARDA in Syria to improve winter hardiness of the crop.

Lentil cultivation in traditional areas, including northern Africa, the Middle East, Ethiopia, and the Indian subcontinent, range from fully mechanized to fully traditional. Planting dates are from November to December and usually follow cereal planting. Soils are generally plowed in summer and cover-cropped until planting time, although planting on untilled land is also practiced, especially by subsistence farmers or on fields that are not machine accessible.

Planting rate varies from 40 to 90 kg/ha, depending on whether the seed is broadcast or planted in rows. If planted in rows, the spacing varies widely (from 20 cm to 2 m). Often, lentils are planted in pairs of rows, with

20 cm separating each row and 80 cm separating adjacent pairs. This spacing allows cultivation between rows to eliminate weeds. Mechanized planting with cereal drills is becoming more common and inter-row spacings of 40–50 cm are usually used. In traditional production systems, herbicides are not used; hand weeding is often practiced, with the weeds then used as animal feed.

Lentil harvest is most often accomplished by hand pulling and piling the plants in the field for drying. The piles are then collected and taken to a central threshing facility. Threshing is usually done by animals and animal-drawn disks, which continually pass over the piles of plants until the seeds are separated from the pods. The threshed material is winnowed to separate the seeds from the straw and other plant debris. The residues from winnowing are valued as feed for livestock and often command a price equal

Table 3. Area sown, average seed yield, and total production of lentils in various countries in 1990

Country	Area sown (1,000 ha)	Seed yield (kg/ha)	Production (1,000 t)
Argentina	25	880	22
Bangladesh	210	771	162
Canada	139	1,572	219
Chile	14	589	8
Egypt	6	2,701	16
India	1,095	641	703
Iran	107	477	51
Morocco	63	523	33
Pakistan	80	475	38
Spain	47	577	27
Syria	144	701	101
Turkey	900	1,000	900
USA	42	952	40
Commonwealth of Independent States	53	943	50

SOURCE: Food and Agriculture Organization 1991.

to or greater than that of the seeds (Erskine, personal communication 1992). Most of the seed crop harvest is consumed locally, but the excess is sometimes exported. These traditional methods of lentil production and harvest are slowly giving way to mechanized culture, including seed drills, rollers, herbicide applications, mowing machines, stationary threshers, and in some cases, combines.

Taxonomic and Historical Perspectives

After a confused and complex taxonomic history, lentils were eventually placed in the genus *Lens* Miller. The cultivated form is *Lens culinaris* Medik. spp. *culinaris*. It is within the order Rosales, suborder Rosineae, family Fabaceae, subfamily Papilionaceae, and tribe Viciae. Four wild subspecies are recognized in the genus *Lens*: *L. orientalis*, *L. nigricans*, *L. ervoides*, and *L. odemensis*. Archeological evidence, together with morphological and cytogenetic comparisons, suggest that *L. culinaris* was derived from *L. orientalis* (Zohary 1972, Ladizinsky 1993).

Ladizinsky (1979a) indicated that pod indehiscence of cultivated lentil is governed by a single recessive gene. It is probable that the domestication of lentils was, to a large extent, the result of selection of an indehiscent pod mutant from *L. orientalis* by early agriculturalists (Ladizinsky 1979b). Lentils were probably one of the primary domesticates (as were wheat and barley) on which Neolithic agriculture was founded in the Near East about 8,500 years ago. By the Bronze Age, they had been disseminated throughout the Mediterranean region, Asia, and Europe. Lentils were introduced into the United States in 1916, near Farmington, Washington (Youngman 1967). The commercial production of U.S. lentils today can probably be traced to that introduction of a single landrace. Although generations of farmers and processors have certainly selected better adapted cultivars from that original landrace (for example, by saving seeds for subsequent crops from particularly productive fields or by planting seeds that were sorted for size), the principal goal for modern breeders is to have larger and more stable yields.

Lentil Description

Lentils are slender, semierect annuals, usually between 30 and 45 cm (12–18 inches) tall. Individual plants may vary from single stems to vigorous, bushy forms in

dense or sparse stands. The pinnate leaves are relatively small compared with the trifoliolates of soybean and *Phaseolus* beans and may contain as many as 14 sessile, ovate, elliptic, obvate, or lanceolate leaflets, each about 1–4 cm (0.5–1.5 inches) long. Each leaf is subtended by two small stipules and may or may not terminate in a tendril.

Reproductive nodes generally bear single flowers, sometimes two or three and, rarely, four flowered racemes on short peduncles. The typical butterfly-like (papilionaceous) flowers are small, from 4 to 8 mm (less than $\frac{1}{2}$ inch) long, and white, pale purple, or purple black. Flowering in lentils proceeds acropetally, so lower nodes may bear pods close to maturity while younger nodes continue to initiate flowers. The flowers are self-pollinated, with cross-pollination vectored by thrips or other small insects but not by wind or honeybees. Outcrossings due to small insects are estimated to be less than 0.8 percent (Wilson and Law 1972). Pollination occurs before the flower opens. After opening, the corolla fades within 3 days, and the fruits or pods are visible 3–4 days later. The oblong pods are flattened, smooth, 1–2 cm ($\frac{1}{2}$ – $\frac{3}{4}$ inch) long, and usually contain 1 or 2, but rarely 3, seeds. Lentil seeds are often divided into two types, as originally described by Barulina (1930) as follows (fig. 1):

Macrosperma—found mainly in the Mediterranean region and the New World, have large seeds [6–9 mm (less than $\frac{1}{2}$ inch) in diameter], normally yellow cotyledons, and little or no pigmentation in the flowers or vegetative structures.

Microsperma—found mainly in the Indian subcontinent and the Near East, have smaller seeds [2–6 mm (less than $\frac{1}{4}$ inch) in diameter], red, orange, or yellow cotyledons, and are characterized by plants that are shorter and more pigmented with smaller pods, leaves, and leaflets.

Lentil seeds are lens shaped and weigh about 2–8 g per 100 ($\frac{1}{8}$ – $\frac{1}{4}$ oz per 100). Testa colors range from pale tan to brown and black, with purple and black mottles or speckles common to some cultivars (Duke 1981). The seeds are rich in protein with concentrations averaging 26 percent. However, as is often the case in grain legumes, there is a shortage of tryptophan and the sulfur-containing amino acids, methionine, and cystine (Adsule et al. 1989).

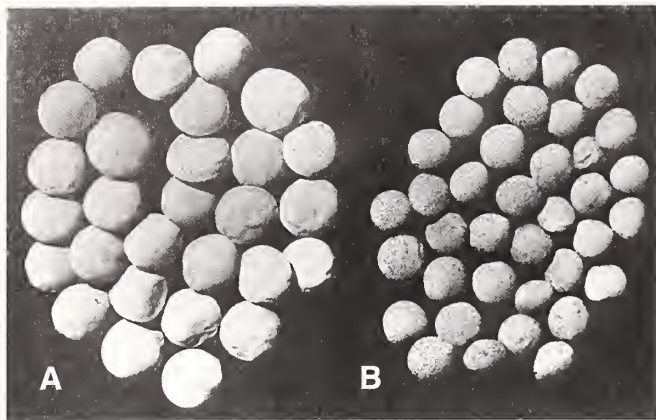


Figure 1. Lentil seed types: A, Macroserma. B, Microserma.

The protein in lentils contains significant concentrations of lysine, a limiting amino acid in cereals. Cereals are relatively rich in tryptophan and the sulfur-containing amino acids. Therefore, when cereals and lentils are consumed together in a balanced diet, they provide adequate amounts of essential amino acids in the human diet. Seed composition varies with genotype and seed maturity and is influenced by soil nutrient availability (Summerfield 1981a, Summerfield and Muehlbauer 1982). These differences are known to affect the cooking time of mature seeds. Improvement in protein quantity or quality is unlikely to be an important breeding objective. Increased quantities of protein from grain legume crops, including lentils, is most likely to result from breeding efforts directed toward increased economic yield and stability of yield between sites and years, rather than from breeding for increased protein content within lines (Boulter 1977). Lentil seeds are more susceptible to mechanical damage than field peas, faba beans, and chickpeas. However, germination is hypogeal (cotyledons remain below the ground), which helps prevent environmental damage to seedlings. In the event of shoot damage, new lateral branches can initiate from nodes below ground.

Lentils are nodulated following infection by *Rhizobium leguminosarum*, the same species that nodulates pea and faba bean. Nodules are elongate and seldom exceed 5 mm ($\frac{1}{4}$ inch) in length (Summerfield 1981a). Yield responses to artificial inoculation may or may not be favorable depending on soil type, availability of inorganic nitrogen, and previous crops.

Further information concerning the genetics, breeding methods, and hybridization of lentils can be found in Muehlbauer et al. (1980), Muehlbauer and Slinkard (1981), Ladizinsky et al. (1985), and Muehlbauer et al. (1985, 1988).

Lentil Culture

Land Requirements

Lentils are grown in sandy loam soils, alluviums, black cotton soils, or in much heavier soils. They may be grown in moderately alkaline or saline soils; nutrient deficiencies (for example, phosphate) are common. However, researchers are still unsure of the precise nutrient requirements of a lentil crop. A general consensus suggests that molybdenum, sulfur, and phosphorus are critical elements for good yields. Interactions with the available water supply also have a large effect on the need and use of minerals by the plant (Summerfield 1981a).

Knowledge of dinitrogen fixation in lentil is based largely on systematic work done since 1978. Although *Rhizobium leguminosarum* is often indigenous to the areas where lentils are grown, crops inoculated with specific strains have sometimes been more productive, depending on the host cultivars. Various studies of dinitrogen fixation by lentil have indicated values ranging from 35 to 115 kg/ha (31–103 lb/acre). Values at the lower end of this range would lead to an average lentil crop that depletes soil nitrogen. Other work indicates that for well-nodulated crops, the fertilizer needs of a subsequent cereal can be reduced if the preceding crop is lentils rather than nonlegumes.

Palouse lentil crops are usually sown in the spring in a 2-year rotation alternating with winter wheat or in a 3-year rotation alternating with winter wheat or barley. Lentils are commonly followed by winter wheat because the moisture they remove from the soil is usually fully replenished by fall and winter rains.

Lentil crops in the Palouse yield best when grown on well-drained soils on south- and east-facing slopes. Dry seedbeds should be avoided, as should those areas which remain waterlogged until late in the season.

Seed Quality and Seed Treatment

For optimum stands and yields, growers must use good-quality seed. They should use seed that is certified for minimum standards of germination (greater than 90 percent), free of weed seed and foreign matter, and treated with seed protectants. In the Palouse, foundation seed of varieties can be obtained directly from the Washington State Crop Improvement Association¹ or the University of Idaho Foundation Seed Program.² Registered and certified seed may be obtained from seed companies or the processors of the commodity. The names and addresses may be obtained from the USA Dry Pea and Lentil Industry Office (see appendix for address).

Seeds of *Vicia* spp. have recently appeared in seed lots of lentils harvested throughout the region. *Vicia* seeds are considered contaminants in lentil crops and contribute to reduced grades. The seeds are about the same size, shape, and color as those of the lentil cultivar 'Brewer', but they have a blunt edge and a more distinct hilum region. In the field, *Vicia* rogues are distinctive for their conspicuous blue or purple flowers, pointed pubescent leaflets, and elongated pods containing up to seven seeds. The *Vicia* rogue problem can be virtually eliminated through the use of certified seed.

Seed treatments with appropriate fungicides, such as captan or metalaxyl, will prevent damping-off and ensure good stands. Treatment of the seed with an insecticide such as lindane is beneficial for the control of wireworms and seedcorn maggots. Molybdenum is often applied along with the other seed dressings. If lentils are to be sown in regions outside the Palouse, *Rhizobium leguminosarum* must be placed with the seed to ensure good root nodulation and dinitrogen fixation.

Seedbed Preparation

Fields intended for lentils are usually chisel plowed in the fall to aid water infiltration, control erosion, and maximize the retention of crop residues. Tillage along the contours of hills improves moisture infiltration and prevents excessive runoff and soil erosion (Papendick and Miller 1977). In the spring, when soils are sufficiently dry, fields should be cultivated and firmed with a spring-tooth harrow or a rod weeder. Deep tillage leads to excessive loss of moisture and should be avoided. A well-prepared seedbed will have some crop residues on the surface, which improves water infiltration and reduces the erosive effects of rainfall. Excessive residues interfere with placing seeds at a uniform depth. Soil temperatures increase quickly when fields are well prepared, resulting in rapid germination, good emergence, and improved seedling growth.

Seeding

Lentils are often planted in early spring with double disk drills, the same equipment used to seed cereals. Experience in the Palouse is typical of that elsewhere: Yield advantages due to early planting can be substantial, provided seeds are not "mudded in" by attempting to plant when the soil is too wet (Entenman and Youngman 1968).

Studies indicate that a seeding depth of 4–5 cm (1.5–2 inches) is optimal for germination and growth, even though deeper plantings may have better access to soil moisture and improved protection from frost. Despite some success with deeper plantings, plant emergence may be poor due to soil compaction from farm machinery or heavy rains. Lentil seeds can germinate in the light or the dark and in constant or diurnally fluctuating temperature regimes. However, rates of germination, emergence, and seedling growth are markedly affected by temperature. Optimum values for germination and growth vary with cultivar, age, and size of seeds. Smaller seeded cultivars germinate more rapidly than larger ones at temperatures between 15 °C and 25 °C (60–77 °F) (Saint-Clair 1972).

The successive stages of canopy formation (stem elongation, leaf initiation, leaf expansion, and branching) have different optimal thermal regimes, which obviously affect the rates at which these processes occur. This may explain a common observation by

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farmers that lentil seedlings, once emerged, often grow slowly, if at all, for several days or even weeks (for example, successive stages of vegetative development have warmer temperature optima).

Many studies show that lentil yields are remarkably stable over a wide range of population densities. The plants are able to fill available space by initiating lateral branches and, thus, can compensate for poor emergence and thin stands. Recommended seeding rates for Palouse farmers are 67–79 kg/ha (60–70 lb/acre) for the most commonly grown cultivar ‘Brewer’ (Morrison and Muehlbauer 1986). Elsewhere, seeding rates vary from 15 kg/ha (13 lb/acre) in northern India to 115 kg/ha (103 lb/acre) for irrigated crops in Egypt (Hawtin et al. 1980). It is always important to use seeds of good quality and a seeding rate large enough to ensure good stands in case the crop should suffer adverse environmental conditions, resulting in poor emergence and disrupted seedling distribution. Optimum plant density has been estimated at 90 plants/m² (8.3 plants/ft²) (Muehlbauer 1973).

It is important to select plant populations appropriate for dryland farming systems. Smaller seeded cultivars are considered to be more tolerant of drought than the larger seeded ones because they often mature more rapidly, thus avoiding extreme water stress. The development of drought-tolerant cultivars deserves to be given priority in lentil research. Without a doubt, the success of lentils as an internationally important crop depends greatly upon the production of economically attractive and reliable yields when the water supply is limited.

Lentil Cultivars

The few lentil cultivars released before the 1980’s were generally selections from germplasm collections and not from hybridization programs (Hawtin et al. 1980). Today, national and international lentil improvement programs provide much-improved resources for hybridization and selection. Each of these programs acknowledges the importance of collecting, introducing, exchanging, and maintaining germplasm to provide the widest range of genetic diversity in breeding programs. Thus, with greater attention worldwide and with ongoing nationally and regionally supported programs, improved cultivars with larger yield potential are increasingly available.

Here are cultivars currently used by growers in the Palouse—

‘Chilean 78’ is a composite of pureline selections from ‘Chilean’, which were made to remove off-type lentils and *Vicia* rogues from the seed stock. The ‘Chilean’ stock was the most commonly grown type in the region until the release of ‘Chilean 78’.

‘Brewer’, developed in the hybridization program and released in 1984, has largely replaced common ‘Chilean’ and ‘Chilean 78’ (Muehlbauer 1987). ‘Brewer’ has yellow cotyledons and larger, more uniform seeds, matures 4–7 days earlier, and gives consistently higher yields than ‘Chilean’ (23 percent greater in yield trials). It is currently the main cultivar grown in the Palouse region.

‘Redchief’, released in 1980, is a large, red cotyledon-type cultivar with seedcoats that lack mottling (Wilson and Muehlbauer 1983). Its yields are consistently better than ‘Chilean’ or ‘Chilean 78’. The domestic market for large, red lentils is expanding in the United States following the introduction of ‘Redchief’.

‘Emerald’, released in 1986, is a bright, green-seeded cultivar with distinctive green cotyledons. Its production is directed at speciality markets (Muehlbauer 1987).

‘Palouse’ is a large, yellow cotyledon-type cultivar that was developed through hybridization and selection for seed size, absence of seedcoat mottle, and early maturity (Muehlbauer 1992). It produces yields comparable to ‘Brewer’ and is resistant to mechanical damage during threshing and processing.

‘Crimson’ is a small-seeded, red cotyledon-type cultivar, released in 1990 (Muehlbauer 1990). Its source was a pureline selection from ‘Giza-9’, a cultivar developed in Egypt. It is anticipated that small, red cotyledon-type cultivars will find a place in the export market.

‘Spanish Brown’ or ‘Pardina’ is a small, yellow cotyledon-type cultivar with brown and speckled seedcoats. It was introduced from Spain and is now being produced extensively in the Palouse. It has produced exceptionally good yields, although recent observations indicate susceptibility to *Ascochyta* blight caused by *Ascochyta fabae* f. sp. *lentis*.

Other cultivars include 'Laird' (has some Ascochyta blight resistance and large, unmottled seed) (Slinkard and Bhatti 1979), 'Eston' (small, pale-colored seed), 'Rose' (red cotyledons), and 'Indianhead' (small seeded with black seedcoats) from Canada; 'Precoz' (an early variety) from Argentina (Riva 1975); 'Araucana-INIA' (rust tolerant) from Chile (Tay et al. 1981) and 'Tekoa' (a U.S. release grown in Chile because of its resistance to rust); 'Pant L-234' (*Fusarium* resistant) (Kamboj et al. 1990), 'Pant-209' and 'Pant-406' from India; and 'Giza-9' from Egypt (Hawtin et al. 1980).

Fertilization and Pest Control

Fertilizers

Although researchers are not yet certain of the nutrients required by productive lentil crops, worldwide experience has prompted advisers to recommend applications of the following fertilizers as economically worthwhile "insurance" for growers: (1) molybdenum (applied as a seed dressing and essential for good nodulation and dinitrogen fixation); (2) sulfur (additions improve seed concentrations of the nutritionally limiting S-amino acids); (3) phosphorus (also essential for good symbiotic performance and overall plant growth); and, occasionally, (4) potassium.

Recommended application rates are—

- Molybdenum—sodium molybdate as a seed dressing at 35 g/ha (0.5 oz/acre).
- Sulfur—applied to crops grown in rotation with lentils at 17–22 kg/ha (15–20 lb/acre) on deficient soils.
- Phosphorus—if soil tests (acetate extract) reveal phosphorus concentrations at 4 parts per million or less, apply at 44–66 kg/ha (39–59 lb/acre). Strong responses are common on severely eroded soils.
- Potassium—on sandy or severely eroded soils, 22 kg/ha (20 lb/acre) of potassium oxide may prove beneficial for yield and improve the cooking qualities of seeds (Wassimi et al. 1978).
- Nitrogen—effectively nodulated lentil crops seldom respond to an application of inorganic nitrogen fertilizer.

The "nitrogen hunger" phase, which is often experienced by grain legumes when crops are seeded early into cool, wet soil before significant symbiotic dinitrogen fixation begins, can be avoided by the application of a small starter dose of 10–25 kg/ha (9–23 lb/acre) inorganic nitrogen fertilizer placed adjacent to, but not in contact with, the seeds (Saxena 1981). Inoculation with an appropriate strain of *Rhizobium leguminosarum* is necessary when lentils are seeded into fields for the first time or after a lapse of several years. Special care should be taken when using fungicide seed dressings potentially toxic to *Rhizobium*. The amount of nutrients removed by an average lentil crop depends on the relative contribution of symbiotic dinitrogen fixation and the uptake of inorganic nitrogen (table 4). Comparing these data with those of other lentil crops grown in a range of edaphic conditions and locations may determine if different cultivars assimilate into seeds with similar or substantially different amounts of these elements.

Weed Control

Lentils compete poorly with weeds for light, water, and nutrients. During early stages of vegetative growth and in cool weather, lentil growth rates are slow and weeds can quickly overgrow the crop. If not adequately controlled, weed infestations can reduce yields by as much as 75 percent. Although the period of crop growth during which competition is most deleterious varies in different locations, competition from weeds is usually serious and requires some form of control in order to produce good seed yields.

Hand weeding or mechanical cultivation is not practical because both of these methods can damage lentil seedlings, increase the incidence of stem and root diseases, and stimulate more weed seeds to germinate, which can then create additional problems. Harrowing or rotary hoeing after emergence has been evaluated, but even this light tillage operation did not improve weed control (Boerboom, unpublished data 1992).

Research has shown that some herbicide formulations are effective with lentils, but there are only a limited number of products registered for use in lentils in the United States (table 5). Because of this limited herbicide availability, along with lack of crop competitiveness, the broad spectrum of weeds requiring control, and unpredictable rainfall, the control of grass and especially broadleaf weeds is sometimes erratic.

Table 4. Nutrients removed in lentil and soybean fields for each 1,000 kg/ha of harvested seed

Crop	Nutrients (kg/1,000 kg seeds)					
	N	P	K	Ca	Mg	S
Lentil*	43	5.0	11.7	0.7	1.2	2.0
Soybean†	71	6.1	20.3	3.0	3.0	1.7

Note: All data were converted to elemental equivalents to facilitate comparisons.

* Means for cultivars 'Chilean 78', 'Tekoa', and 'Brewer'.

† Data for U.S. soybeans included for comparison (Scott and Aldrich 1970).

Wild oats, volunteer cereals, and other annual grasses are common and serious weeds in lentil crops. Wild oats can be controlled with preplant-incorporated applications of triallate. After crop emergence, sethoxydim applications will control annual and perennial grasses.

For broadleaf weed control, imazethapyr can be applied before planting followed by shallow incorporation or applied preemergence after planting. Metribuzin can be applied either preemergence or postemergence or as a split application. Metribuzin has given good to excellent control of a wide spectrum of broadleaf weeds with few exceptions. Preemergence applications of both herbicides require adequate rainfall to distribute the herbicide into the zone where weed seeds germinate. With excessive rainfall and on soils with low organic matter, metribuzin may leach deeper into the profile and cause crop injury. Injury is most severe on the tops of eroded hills where soils have low organic matter and lentils may have been seeded too shallowly.

Red lentils, such as 'Crimson', can be grown successfully in areas of lower rainfall, but dry conditions reduce the effectiveness of soil-active herbicides, so weed control may be poor.

It is always important that growers refer to herbicide labels for application directions, rates, and precautions. Precautions should also be taken when applying sulfonylurea or phenoxy herbicides to cereal crops adjacent to lentil fields, as lentils can be severely injured by drifts from these herbicides.

Residuals of sulfonylurea herbicides in soils planted in lentils can be especially damaging to the crop.

Insects

Lentils are attacked by insects wherever they are cultivated. Preharvest pests include soil insects that attack seeds soon after planting or that attack the stems and roots of seedlings. These include seedcorn maggots [*Delia platura* (Meigen)], wireworms (*Limoniusspp.* and *Ctenicera spp.*), cutworms (*Agrotis spp.*), and larvae of weevils (*Sitona spp.*). Thrips (*Frankliniella spp.*), aphids [*Aphis craccivora* (Koch) and *Acyrtosiphon pisum* (Harris)], leaf weevils [*Sitona lineatus* (L.)], lepidopterous larvae (*Helicoverpa* and *Spodoptera spp.*), and grasshoppers feed on leaves, stems, and flowers.

Worldwide, the most important insects that damage pods and seeds are lygus bugs (*Lygus spp.*), bruchid beetles (*Bruchus spp.* and *Callosobruchus spp.*), and lepidopteran pod borers [*Helicoverpa armigera* (Hüb.), *Cydia nigricana* (F.), and *Etiella zinckenella* (Treitschke)]. Bruchid beetles are also major postharvest pests, except in the United States. The contribution by van Emden (1988) is a useful general reference on worldwide insect pests of lentils and other grain legumes.

Economically important pests of lentils in the Palouse region are pea aphids (*A. pisum*), cowpea aphids (*A. craccivora*), lygus bugs, western yellow-striped armyworms [*Spodoptera praefica* (Grote)], and, to some extent, seedcorn maggots and wireworms. Table 6 lists the insecticides registered for control of these pests in lentils in the United States.

Table 5. Herbicides for weed control in lentils

Target weeds	Herbicide	Application	Mechanism of action
Broadleaf	Imazethapyr	Preplant incorporation or preemergence	Inhibits amino acid synthesis
Broadleaf	Metribuzin	preemergence pre- and/or postemergence	Inhibits photosynthesis
Grass	Sethoxydim	postemergence	Inhibits fatty acid synthesis
Wild oat	Triallate	Preplant incorporation	Inhibits fatty acid synthesis

SOURCE: William et al. 1992.

Lentil fields in the Palouse can be devastated by aphid-vectored pathogenic viruses (see "Diseases," following) and feeding damage when pea aphid densities intermittently reach outbreak levels. The cowpea aphid (black and smaller than the light-green pea aphid) damages lentils through direct feeding; its role in vectoring viruses is poorly understood. Several factors seem to favor pea aphid outbreaks: (1) fall buildup of aphids on alfalfa and other perennial host plants, (2) mild fall and early winter temperatures favoring abundant egg laying and thus a large overwintering population, (3) mild winter temperatures, and (4) spring conditions conducive to early movement of aphids from overwintering hosts to lentils (Homan et al. 1991).

Aphids have many natural enemies, including lady bird beetles, parasitic wasps, lacewings, and syrphid flies, but chemical control may be necessary if these insects do not keep aphids at subeconomic levels. Insecticide treatment for pea aphid control should be considered (1) when an economic threshold of 30–40 aphids are collected per 180° sweep of a 38-cm (15-inch) diameter insect net, (2) when few natural enemies are present, and (3) when aphid numbers do not decline over a 2-day period (Homan et al. 1991).

Lygus bug feeding on the immature reproductive structures of lentils causes seed and pod abortion, as

well as a serious seed-quality problem known as "chalky spot" in crops grown in northern Idaho and eastern Washington (Summerfield et al. 1982). Lygus bugs feed with piercing, sucking mouthparts and inject toxic saliva into the immature seed. This forms a depression around the feeding area and leaves a chalky blemish (fig. 2). Adult lygus bug activity can be monitored during blooming and podding by making 25 180° sweeps in at least 5 randomly selected places in a field. Chemical control is warranted when 7–10 adults are collected per 25 sweeps (O'Keefe et al. 1991).

The western yellow-striped armyworm is usually a late-season pest. When heavy infestation develops, larvae can defoliate plants and consume pods. Insecticides containing *Bacillus thuringiensis*, a naturally occurring bacterium that infects lepidopterous larvae and other pest insects, can be used to control damaging populations.

Diseases

Lentils appear to suffer less from diseases than many other grain legumes. Some of the more serious problems are discussed next.

Root rot/wilt complex. Probably the most important disease problems of lentils worldwide are root rots and

Table 6. Insecticides registered for pest control in lentils

Target insect	Insecticide	Preharvest interval (days)
Aphids	Dimethoate	0
	Malathion	3
	Methyl parathion	15
	Methyl parathion	10
	Esfenvalerate	21
Lygus bugs	Dimethoate	14
	Methyl parathion	15
Western yellow-striped armyworms	<i>Bacillus thuringiensis</i> (b.t.)	see manufacturer's directions
	Methomyl	21
Wireworms	Lindane	seed pretreatment
Seedcorn maggots	Lindane	seed pretreatment

SOURCE: Fisher et al. 1992.

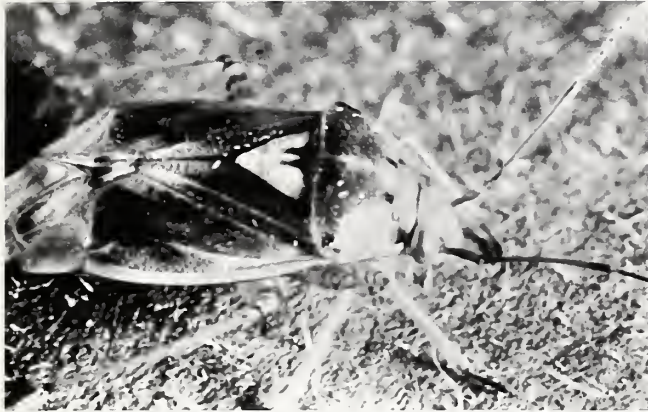
Note: Do not use insecticide-treated foliage for animal fodder. Always follow label directions and precautions when using insecticides. Because rules and regulations governing the use of pesticides are continually changing, it is advisable to check with experiment station personnel, pesticide suppliers, or other authorities before using any of these insecticides.

wilts caused by *Pythium*, *Rhizoctonia*, *Sclerotium*, and *Fusarium* species (Kaiser 1987). Research is under way to select strains resistant to the various components of the complex. Inheritance of resistance to *Fusarium* wilt has recently been reported in germplasm from India (Kamboj et al. 1990).

Two other important diseases of lentil in many countries are rust and ascochyta blight, especially in wetter areas or during years with heavy rainfall.

Rust. Rust, caused by *Uromyces viciae-fabae* Pers., is a serious problem in areas with mild temperatures and humid conditions. Some sources of resistance have been identified, and progress toward developing resistant cultivars is being made (Khare 1981). Fortunately, rust of lentils has not yet appeared in the Palouse region.

Ascochyta blight. Blight caused by *Ascochyta fabae* Speg. f. sp. *lentis* Gossen, a seedborne disease, causes severe damage in many cool, wet regions (fig. 3). Work in several countries has identified good sources of resistance and these lines are being incorporated into breeding programs. Ascochyta blight is becoming a major problem in the United States, and it continues to be an economic problem in the lentil-producing areas of Canada. Breeding programs have been initiated to introduce into other lentil cultivars the resistance shown by the cultivar 'Laird' (Slinkard, personal communication 1991). Infected seed may be treated with thiabendazole to reduce the incidence of seedborne *A. fabae* f. sp. *lentis*, but the compound is not registered for use on lentils in the United States (Kaiser 1987).



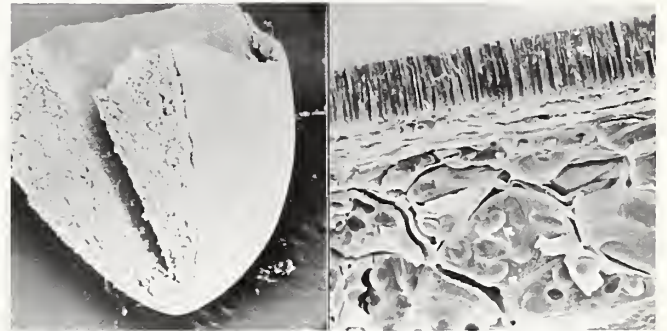
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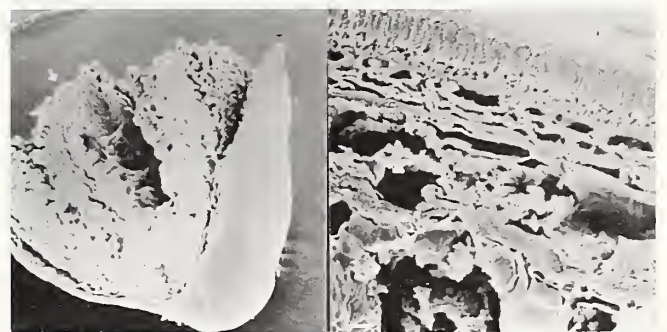
B



C



D



E

Figure 2. The lygus bug and chalky spot in lentils.
A, Mature lygus bug. B, Scanning electron micrograph of lygus bug piercing and sucking mouth parts.
C, Chalky spot in lentil seeds (left); normal seeds (right). D, Internal view of healthy seed. E, Internal view of seed affected with chalky spot.

Seedborne fungi. In the Palouse, reduced seed quality can result from infection by different pathogenic fungi, some of which are also pathogens of chickpeas and peas (Kaiser 1992). The incidence of fungi associated with commercial lentil seeds in the Palouse varies greatly from year to year and is influenced by weather conditions, particularly rainfall. The seedborne pathogens most frequently isolated from discolored Palouse-grown lentil seeds are *Botrytis cinerea*, *Phoma medicaginis* var. *pinodella* (= *Ascochyta pinodella*), and two *Fusarium* species—*F. acuminatum* and *F. avenaceum*. The amount of rainfall during July, when the crop is approaching maturity or about to be harvested, appears to affect the incidence, prevalence, and severity of seedborne pathogenic fungi. If exces-

sive rainfall occurs during harvest or when plants are drying in windrows, lentils that remain on or near the moist soil surface may show seed discoloration from colonization and infection of the pods and seeds by pathogenic and saprophytic fungi.

Viruses. Viruses are major disease problems in the Palouse. Most viruses that infect peas also infect lentils. These include alfalfa mosaic, bean (pea) leaf roll virus (BLRV), bean yellow mosaic, pea enation mosaic virus (PEMV), and pea streak. These viruses are transmitted by pea aphids, generally from infected alfalfa and clover plants. Control of common viruses is best achieved by planting resistant cultivars. Control



A



C



B

Figure 3. Ascochyta blight on lentils.
A, Leaves and stem. B, Pods. C, Seeds.

of the aphid vectors is not generally recommended, as the economic thresholds for the insects are not known and insecticides are often ineffective in halting the spread of stylet-borne viruses.

In the Palouse region, PEMV and BLRV are the most important virus diseases of lentil, but the crop is also a host of pea seedborne mosaic virus (PSbMV). PSbMV may cause stunting and malformation of leaves, stems, flowers, and fruits. There may also be a reduction in yield and the production of smaller, misshapen seeds. Sources of resistance to PSbMV have been identified and are now being used in the development of new lentil cultivars (Kaiser 1987). Sources of tolerance to PEMV have also been identified (Muehlbauer, personal observations 1991) and are being incorporated into improved cultivars.

Harvesting and Marketing

Harvesting

Harvesting often poses problems and may represent a major constraint to lentil production in traditional farming systems. To avoid loss of seeds due to shattering, many farmers in developing countries pull the crop by hand before it is completely mature and lay the plants in the field to dry. Hand harvesting is uneconomical, so mechanizing lentil production has become an important goal for national and international research programs. To facilitate mechanical harvest, germplasm has been evaluated for taller, nonlodging plant types with nonshattering pods. These evaluations have been only partially successful in reducing seed losses at harvest. Development of equipment to harvest lentil crops in marginal areas must take into account short plant stature, stony soils, and uneven soil surfaces. Equipment has been designed and tested that holds promise for future mechanization of lentil crops (Saxena and Goldsworthy 1988).

Palouse farmers generally harvest lentils by mowing and swath-ing, or they may combine the crop. Swath-ing is often necessary to kill green weeds and allow them to dry so the lentils can be threshed efficiently. Plants are usually swathed when the pods turn a cream to golden color; then older pods will be dry and their seeds firm. Harvesting prematurely does not allow the seeds to fully mature, and harvesting too late, when pods are overripe, can cause them to shatter. Moden et al. (1986) showed there can be losses of up to 55 percent

of the potential lentil harvest, one-third due to pod shatter. This problem can be minimized by mowing at night or early in the morning when relative humidities are high and dew deposits are present. If lentils are cut prematurely or if they receive rain, the windrows must be turned to allow uniform drying and prevent fungal attack.

Swathed lentils can normally be combined 10–14 days after mowing. The same combines used for cereals, with a pickup attachment (pea bar), are used to pick up the plant material. Successful combining can be achieved when the seeds are “hard” (that is, the seeds will not dent when bitten) and the cylinder speed and concave spacing are adjusted to prevent the seeds from cracking or breaking during threshing. Airflow rates should be adjusted to blow out chaff but not seeds. Machine groundspeed should be maintained close to 2.5 km/hr (1.5 mi/hr).

Marketing

Palouse lentil crops are graded according to standards set up by the U.S. Department of Agriculture, Grain Inspection, Packers, and Stockyards Administration, in close cooperation with producers and processors. These standards are based on sieve size, contaminants, moisture content, and other quality characters. Graded seeds allow orderly marketing and are used by sellers and buyers to determine price.

The increase in world population and the displacement of lentils by cereals in traditional production areas point out the need to increase lentil production in nontraditional areas. In general, worldwide lentil yields have not increased significantly, but the loss of production in traditional areas has been largely offset by expanded production in Turkey and Canada. These two countries have dramatically increased their production and are the world’s largest exporters.

Lentils contribute significantly to farm economics in the Palouse and the United States as a whole. The lentil crop, during the last decade, averaged over 54,400 metric tons with an approximate value of \$31.7 million annually. About 80 percent of U.S. lentils are exported. Principal markets for Palouse-grown lentils are Spain, Peru, Ethiopia, and Venezuela.

Collaboration, Cooperation, and Communication

Research and sales promotion are important to lentil-producing operations. International research organizations, such as ICARDA, and the national programs of many countries try to provide information necessary for improvements in lentil farming. These international and national efforts must be coordinated to produce the maximum benefit (see appendix).

The newsletter, *LENS*, published since 1974, furnishes an excellent medium for communication among lentil researchers. Other publications and workshops have further stimulated work on the crop. The impressive gains made during the last decade must now be extended to improve lentil production and marketing in the demanding years ahead.

As the international lentil literature was reviewed, it became apparent that a uniform system for units of measurement must be used in descriptions of research and production. The authors used the System International d'Unites (SI) with English system equivalents in parentheses. A global acceptance of the growth-stage descriptors described by Erskine et al. (1990) is also encouraged.

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Lentils in the Palouse

Growers recognize the importance of foreign and domestic sales promotion and research as necessary elements of their overall operations. New markets must be created for the expanding industry. Palouse growers have united with processors and exporters into a single organization, the USA Dry Pea and Lentil Industry. The industry comprises the Washington and Idaho State Dry Pea and Lentil Commissions, which administer project funding, and the USA Dry Pea and Lentil Council. The USA Dry Pea and Lentil Council consists of a processor/exporter division, which promotes domestic and foreign marketing, and a grower division, which engages in industry lobbying. The USA Dry Pea and Lentil Industry employs a professional staff to administer their programs.

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Lentils Elsewhere

The International Center for Agricultural Research in the Dry Areas (ICARDA) is a member of the world network of international agricultural research centers. The center has a world mandate for the improvement of lentil and barley crops and the agricultural systems in which they are grown, and a joint mandate for chickpeas with the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) located in India.

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The Grain Legume Genetics and Physiology Research Unit conducts regional research to understand the genetic properties and develop improved cultivars of edible grain legumes, including lentils.

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